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Effect of Using Ensilaged Corn Wet Distillers' Grains Plus Solubles (WDGS) as a Partial Replacement for Concentrated Feed for Wet Lot Fed Fatteners during Fattening on Growth Performance, Carcass Characteristics and Pork Quality

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Simple Summary: Wet Distillers' Grains plus Solubles (WDGS) is characterized by a high concentration of crude protein and crude fat on a dry matter basis (DM), which makes them a valuable feed source for pigs. Because of that, WDGS can replace some amounts of the protein components and cereal grains of feed. Preservation based on ensiling improves the nutritional value of WDGS through enhancing its digestibility. This study reveals that utilizing 20% WDGS may have a detrimental effect on feed intake. WDGS did not affect growth performance or the quality and the nutritional value of the pork.

Abstract: The purpose of this study was to determine the nutritional suitability of WDGS in pigs' feeding and production. Pigs were liquid fed and divided into 3 groups. Pigs in the control group were fed diets based on cereal grains, while the experimental groups were also given 10% or 15% WDGS, which partially replaced their cereal grains. During this study, the average daily gains (ADG), feed intake, chemical composition of meat, fatty acid profile of meat, and quality parameters of the carcass and meat were examined. The highest statistical weight gains were detected for the group WDGS 10% during the first stage of the fattening period. No statistical differences were detected for the final body weight, carcass traits, chemical composition of the meat or the composition of fatty acids such as SFAs, PUFAs, and MUFAs, with the exception of eicosenoic acid (C20:1n9). Pigs fed on 10% WDGS exhibited lower peroxidation of lipids (TBARS) than the control group or WDGS 15%. Similarly, water holding capacity (WHC) was the lowest for the group WDGS 10%. Of the meat coloration, redness (a*), yellowness (b*), and chroma (C*) were affected by the WDGS' inclusion, where the highest values were observed for the group WDGS 10%. In conclusion, WDGS can be utilized in the liquid feeding of pigs for up to 15% of their DM.

Keywords: WDGS; liquid feeding; fatteners; growth performance; carcass characteristics; meat quality

Citation: Roguski, M.; Łozicki, A.; Sońta, M.; Bendowski, W.; Niemiec, T.; Zglińska, K.; Zielińska-Górska, M. Effect of Using Ensilaged Corn Wet Distillers' Grains Plus Solubles (WDGS) as a Partial Replacement for Concentrated Feed for Wet Lot Fed Fatteners during Fattening on Growth Performance, Carcass Characteristics and Pork Quality. *Agriculture* **2023**, *13*, 2017. https://doi.org/10.3390/agriculture13102017

Academic Editors: Daniel Simeanu and Daniel Mierlita

Received: 31 August 2023
Revised: 5 October 2023
Accepted: 10 October 2023
Published: 18 October 2023

1. Introduction

The bio-ethanol industry delivers ever-increasing amounts of by-products, which are of three general types: condensed corn distillers solubles (CCDS), dried distillers grains plus solubles (DDGS), and wet distillers grains plus solubles (WDGS) [1–3]. Of all the ethanol by-products DDGS and WDGS are the ones that possess the greatest importance for the feed industry and livestock feeding [4]. Currently, DDGS is the main by-product utilized by the animal feed industry that can often be found in commercial mixtures for

farm animals. Its usability as animal feed is highly dependent on the effectiveness of the drying process. As such, any fluctuations in energy resources' prices affect the final production costs of DDGS. Because of that, it may be more profitable for farmers to utilize WDGS instead of DDGS whenever possible [5,6]. Therefore, there is a growing trend in the utilization of WDGS as animal feed, for cattle in particular but also for swine. Unlike DDGS, WDGS is characterized by a rather low dry matter content of around 35–45%, which subsequently may lead to spoilage even after 2 days of storage at 32 °C [7]. Because of that WDGS should either be freshly fed or ensilaged [2]. Nowadays, more and more producers decide to implement wet lot feeding, also known as liquid feeding, into pig production systems. Liquid feeding offers many advantages such as the increased digestibility of the feed, lowered labor intensity and the increased allowance of wet by-products, e.g., milk, whey, or WDGS in the pigs' diets [8], also decreased aggression, which creates better welfare conditions for the animals [9]. Furthermore, fermenting liquid feed also provides a habitat for probiotic lactic acid bacteria, which improve pigs' welfare by reducing *Salmonella* spp. proliferation in the guts [10].

Fresh WDGS exhibits a high nutritional value. The average crude protein concentration is between 25 and 30% DM and average crude fat concentration is 7–12% DM [6,11]. However, WDGS exhibit insufficient amounts of many limiting amino acids for pigs, including lysine, methionine, arginine and threonine, which should be additionally supplemented in the feed [12]. The composition of fat in WDGS also deserves attention, because the high content of PUFA, MUFA, carotenoids and α-tocopherols may affect the physicochemical properties of the obtained meat and fat [13–16]. Therefore, determining the beneficial dose of WDGS in the feed is crucial in the process of universal introduction of this product to pig nutrition.

Due to the fact that WDGS has a feeding value similar to that of DDGS and corn grain, it can potentially be used as a substitute to many feedstuffs rich in energy or protein in pigs' diets. While it has not been confirmed for WDGS, it has been reported that pigs' diets containing 15% DM of DDGS lead to feed refusals and overall reductions in feed intake [17], which can be safely assumed may also occur when WDGS are administered beyond those levels as well. Suffice to say, similarly to DDGS, WDGS should constitute up to 10% DM of a fattener diet [18] so as to avoid its detrimental effects. As such, WDGS may be a suitable component for ensiling and incorporating it into the liquid diets of hogs. Ensiling is an extremely important process for the proper preservation of feedstuff that may spoil or become inappropriate for animal feeding. Ensiling also provides the possibility to utilize feeds that may have been unheard of in pig feeding and nutrition. Apart from WDGS, feeds such as grass [19], corn grains [20] and other agricultural by-products [21] can be easily ensilaged and used as pig feed. It is highly likely that with time those feeds will become even more popular and omnipresent in the liquid feeding of pigs.

Considering the above, the aim of this research was to determine if ensilaged WDGS could be utilized as a suitable component and a substitute to cereal grains or protein feedstuff for fatteners in a wet lot feeding system. The effectiveness of WDGS on animal performance was determined based on physiochemical analyses of meat and animal production yields

2. Materials and Methods

All pigs were handled in accordance with the regulations of the Polish Council on Animal Care and the EU Directive 2010/63/EU of 22 September 2010 [22]. The experiment did not require approval from the 2nd Local Animal Research Ethics Committee in Warsaw as it was performed under the production conditions of a pig-producing farm.

2.1. Animals and Housing

The experiment was conducted on (n = 30) 3-breed Danish fatteners: ♂Duroc × ♀Landrace × Yorkshire. The animals were randomly and equally divided into 3 treatment groups based on sex (barrow to gilt ratio 1:1) and body weight (BW). Each one of the

groups contained 10 fatteners (5 barrows and 5 gilts). Pigs from each group were housed in group pens with mounted plastic grating (1/3 of the total surface of the pen was grated with each head getting 1 m^2 of floor area) in an environmentally controlled building in accordance with Regulation of the Minister for Agriculture and Rural Development (2010) [23]. The experiment was conducted under the following conditions: building was kept at a temperature of 18–19 °C, and relative humidity of up to 70%. Growing fatteners were given liquid feed with a diet containing two different dosages of WDGS at 10% and 15% DM (originally 20% DM). The animals were liquid-fed utilizing automatic feeding and water from the bowl waterer *ad libitum*.

The fattening period was divided into two stages. The 1st stage started when fatteners weighed around 35 kg and finished with fatteners reaching 60–70 kg, while the 2nd stage started when fatteners weighed between 60 and 70 kg and finished with a final body weight of around 130 kg. Before the fattening period started, pigs were subjected to the introductory period where ensilaged WDGS was steadily increased in the pigs' diets. Originally, during the 1st stage of fattening, pigs were to be fed either 10% or 20% of ensilaged WDGS. However, it was observed that the pigs fed diets containing 20% WDGS exhibited lowered feed intake. Because of this fact, the WDGS dosage was lowered to 15%. It is noteworthy that the WDGS dosages of 10% and 15% were stable and used throughout the entire experiment. The weighing of pigs during the experiment was performed individually and every month. Feed intake was collectively calculated for each of the feeding groups, which was later used to determine the feed conversion ratio (FCR).

All pigs were slaughtered in accordance with the standard procedures of the slaughterhouse. All pigs were supervised by a qualified veterinarian.

2.2. Feed Diets

Fatteners were liquid-fed with the use of water as a diluent. The dilution ratio of feed to water was 1 to 2, 1 to 1.6 and 1 to 1.5 for the control group, WDGS 10% group and WDGS 15% group, respectively. Feed mixtures were balanced based on the nutritional requirement of the pigs. The main ingredients of the diet were: barley, triticale and rye middlings, rapeseed and soybean meals, and mineral-vitamin premix with amino acid additives. WDGS was ensilaged prior to the diet mixing, for which the experimental groups contained WDGS at 10% and 15% DM (Table 1). WDGS served as a substitute for grain middling and feeds rich in protein, e.g., soybean post-extraction meal. WDGS exhibited on average 23.4% crude protein, 6.8% crude fat, 11.1% crude fiber and 2.8% crude ash.

2.3. Sampling Conditions

The samples of feed were collected immediately after preparing the liquid feed mixture and kept at +4 °C, until they were dried at 105 °C or frozen at −20 °C, depending on the methodologies. Samples of *Musculus longissimus dorsi* (MLD) were collected 24 h post mortem and stored at +4 °C with the intention of commencing physicochemical analyses while samples destined for chemical analysis were stored at −20 °C.

2.4. Chemical Analyses

Nutritional Value

The chemical composition of both animal feed and meat samples of *Musculus longissimus dorsi*), were determined in compliance with AOAC (2012) [24]: dry matter concentration via drying the samples at 105 °C to constant weight, crude ash via incineration at 550 °C for 6 h, crude protein (Nx6.25) utilizing the micro-Kjeldahl technique (Kjeltec System 1026 Distilling Unit, Foss Tecator, Hilleroed, Denmark), crude fat after extraction with petroleum ether via the Soxhlet method, crude fiber through acid and alkaline hydrolysis via the Henneberg and Stohmann method.

Table 1. Average composition and nutritional value of DM of the diets during the entire fattening period.

Item	Experimental Groups		
	Control	WDGS 10%	WDGS 15%
	% DM Diet		
Barley	20.5	20.5	22.5
Triticale	10	10	10
Rye	50	45	40
Rapeseed meal	5	5	5
Soybean meal (>46 CP)	11	7	5
Corn WDGS	-	10	15
Plant oil	1.0	-	-
Premix *	2.5	2.5	2.5
Nutritional value of 1 kg DM diet			
Metabolic Energy (MJ)	14.50	14.40	14.40
Crude Protein (%)	19.31	19.19	19.20
Crude Fat (%)	2.61	2.76	2.84
Crude Fiber (%)	5.70	5.35	5.79
Crude Ash (%)	4.30	5.00	5.30

* Composition of premix: lysine—12.10%; methionine—2.65%; threonine—5.05%; tryptophan—0.25%; calcium—20.50%; phosphorus—1.80%; sodium—5.00%; iron—4000 mg; manganese—2400 mg; zinc—2600 mg; copper—800 mg; iodine—55.0 mg; selenium—13.50 mg; vitamin A—260,000 IU; vitamin D3—69,000 IU; vitamin E—4700 mg; vitamin K3—68 mg; vitamin B1—68 mg; vitamin B2—170 mg; vitamin B6—105 mg; vitamin B12—830 mcg; vitamin C—1000 mg; folic acid—27.00 mg; pantothenic acid—410 mg; niacinamide B3—690 mcg; biotin—3450 mg; choline chloride—10,000 mg; Aroma, antioxidant: 1b (E320-BHA, E321-BHT, E324—Ethoxyquin) —550 mg/kg; Enzymes: 4a E-1640 6—phytase (EC 3.1.3.2.6 n-5000 FTU/g)—17,500 FTU/kg, (E1600 endo 1,4-beta-xylanase, EC 3.2.1.8—22,000 VU/g; 425,000 VU/kg, endo 1.3 beta-glucanase EC 3.2.1.6—30,000 VU/g, 57,000 VU/kg); raw material composition: calcium carbonate, monocalcium phosphate, (monophosphate) sodium chloride 1.8.1.9, herbal mix 10 g/kg.

2.5. Fatty Acid Composition

The fatty acid composition in extracted fat samples from MLD were analyzed using the gas chromatography flame ionization detection method (GC/FID) according to PN-EN ISO 12966-1:2015 + AC:2015-06 [25], PN-EN ISO 12966-2:2017-05 pkt. 5.2 [26], PN-EN ISO 12966-4:2015-07 [27]. The following fractions were determined: saturated fatty acids (SFA)—C10:0, C12:0, C14:0, C16:0, C17:0, C18:0, C20:0, C23:0; monounsaturated fatty acids (MUFA)—C16:1, C17:1, C18:1 cis 7, C18:1 cis 9, C20:1 cis 9; polyunsaturated fatty acids (PUFA)—C18:2 cis 6, C18:3, C20:2. In addition to fatty acid composition, the atherogenicity index—AI, thrombogenicity index—TI and S/P saturation according to Ulbricht and Southgate (1991) [28] were determined with the following formulas:

$$\mathrm{AI} = \frac{4 \times \mathrm{C14:0} + \mathrm{C16:0}}{\sum \mathrm{MUFA} + \sum \mathrm{PUFA}} \quad (1)$$

$$\mathrm{TI} = \frac{\mathrm{C14:0} + \mathrm{C16:0} + \mathrm{C18:0}}{0.5 \times \sum \mathrm{MUFA} + 0.5 \times \sum \mathrm{PUFA}n6 + 3 \times \sum \mathrm{PUFA}n3 + \frac{\sum \mathrm{PUFA}n3}{\sum \mathrm{PUFA}n6}} \quad (2)$$

$$\mathrm{S/P} = \frac{\mathrm{C14:0} + \mathrm{C16:0} + \mathrm{C18:0}}{\sum \mathrm{MUFA}cis + \sum \mathrm{PUFA}} \quad (3)$$

Also, the hypocholesterolemic fatty acids (DFA) to the hypercholesterolemic fatty acids (OFA) ratio was calculated based on the formula by Fernández et al. (2007) [29].

$$\text{DFA/OFA} = \frac{\text{C18:1} + \text{C18:2} + \text{C18:3} + \text{C20:4} + \text{C20:5} + \text{C22:6}}{\text{C14:0} + \text{C16:0}} \quad (4)$$

2.6. Oxidative Status and Lipid Peroxidation

Oxidative status and lipid peroxidation of the meat was determined using the TBARS assay kit (DTBA-100) by QuaniChrom™ (BioAssay Systems; Hayward, CA, USA). TBARS assay utilizes thiobarbituric acid as a reagent, which detects products of lipid decomposition and peroxidation known as malondialdehydes (MDA). The analysis was performed according to manufacturer's protocol. First, 200 µL of ice-cold phosphate-buffered saline (PBS) was added to 20 mg of pork samples. Then, samples were quickly homogenized so that the 100 µL of the precipitate of each sample could be pipetted out into empty Eppendorf tubes. To each of the vials 200 µL of 10% solution of trichloroacetic acid was added and incubated on ice for 5 min. Afterwards, samples were centrifuged for 5 min at 14,000 rpm, from which 200 µL of supernatants and 200 µL of TBA reagents were pipetted out into new vials to be incubated at 100 °C for 60 min. After that, samples were read in a spectrophotometer (INFINITE M NANO; TECAN™, Männedorf, Switzerland) at A = 535 nm.

2.7. Pork Quality

The color of the muscle was evaluated with a colorimeter (CR-400/410, Konica Minolta; Tokyo, Japan) in accordance with the CIE L*a*b* system. The measurements were performed at three random locations per sample of a 2 cm thick slice of MLD. Hue (b*/a*) and chroma ($\sqrt{}$(a*2 + b*2)) were determined based on a formula provided by Mordenti et al. (2012) [30].

In order to measure drip loss, samples of MLD weighing around 300 g were separately placed into the plastic bags and stored at +4 °C for 24 h. Afterwards, the exudate was emptied from the bags so that it could be weighed, which was later expressed as a relative percentage of the weight sample [31].

WHC was performed on the homogenized samples of meat, which weighed around 300 mg each, in accordance with the methodologies of Grau and Hamm (1952) [32] and Pohja and Ninivarra (1957) [33].

Thermal drip loss was determined using samples of homogenized pork meat weighing between 20 g and 40 g, which then were tightly packed into glass weighing dishes. Subsequently, the samples were submerged and kept at 70 °C for 15 min in a heated bath. After that time, meat samples were taken out of the weighing dishes and left for 24 h so as to allow the water to drip out in order to weight the difference and express it as a relative percentage of the weight sample [34].

2.8. Statistical Analysis

All the data were subjected to heterogeneity and equal distribution tests using Shapiro–Wilk's test and equality of variances using Levene's test. Afterwards, the data were tested by one-factor analysis of variance (ANOVA) or Kruskal–Wallis test if the requirements for the analysis of variance were not met. Tables present the results as mean values ± standard deviations (SDs), standard errors of the means (SEM) and the statistical significance of the group (p-value). Results above $p > 0.05$ were considered to be insignificant. The differences between groups were analyzed using RIR Tuckey's test for ANOVA or the Dunn–Bonferroni test for Kruskal–Wallis.

For the determination of average daily gains, carcass traits, chemical composition of meat, oxidative status of meat and the quality of meat, one-way ANOVA was performed followed by RIR Tuckey's test. However, since the conditions for ANOVA were not met for the fatty acid composition, a non-parametric alternative Kruskal–Wallis test was performed followed by Dunn-Bonferroni test.

All statistical analyses were performed with Statistica ver. 12 software.

3. Results

3.1. Animal Performance and Slaughter Performance

During the first stage of the fattening period fatteners fed 10% WDGS showed significantly higher average daily gains (ADG) than pigs fed 15% WDGS, yet, pigs from the control group displayed similar ADG to the two former groups ($p < 0.05$). For the second stage of the fattening period, no statistical differences between the feeding groups were detected. However, a subtle tendency of increasing ADG was observed for the WDGS 15% group ($p > 0.05$). Throughout the entire fattening, no statistical differences between the feeding groups were detected ($p > 0.05$) (Table 2).

Table 2. Average daily gains (ADG) of fatteners fed WDGS during the fattening period.

Item	Experimental Groups			SEM	*p*-Value
	Control	WDGS 10%	WDGS 15%		
ADG of first stage of fattening period [g]	1218 ^{ab} ± 94.0	1292 ^{b} ± 108.3	1127 ^{a} ± 156.8	26.238	0.0302
ADG of second stage of fattening period [g]	1312 ± 142.1	1401 ± 127.3	1454 ± 122.0	26.777	0.0854
ADG of the entire fattening period [g]	1260± 108.7	1341 ± 104,3	1275 ± 97.8	20.371	0.2322

Numerical values in the same row marked in pairs with letters ab differ at $p \leq 0.05$.

Of all the groups, the WDGS 15% group exhibited higher FCR than the control or WDGS 10% groups (Figure 1).

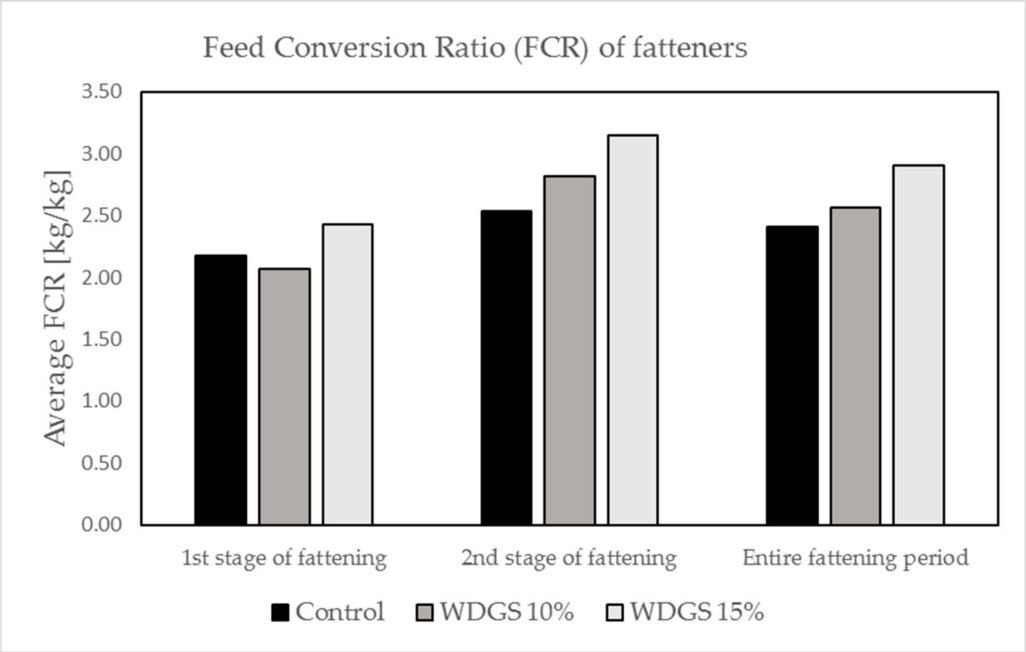

Figure 1. Average feed intake (kg) per weight gained by pigs (kg) throughout the fattening period. Schemes follow the same formatting (FCR).

Table 3 presents the final body weight of fatteners and the parameters of the carcass traits. The final body weight and the carcass traits were overall similar between each of the groups. No statistical differences between any of the groups were detected for the carcass traits ($p > 0.05$).

Table 3. Carcass traits of pigs in the experiment.

Item	Experimental Groups			SEM	*p*-Value
	Control	WDGS 10%	WDGS 15%		
Final body weight [kg]	135.1 ± 8.2	138.5 ± 12.9	132.0 ± 12.1	2.1283	0.5897
Hot carcass weight [kg]	102.6 ± 6.6	104.8 ± 11.1	99.6 ± 10.1	1.7861	0.6358
Dressing percentage [%]	75.9 ± 0.9	75.6 ± 1.6	75.4 ± 1.7	0.2738	0.6653
Meatiness [%]	60.5 ± 1.6	60.8 ± 1.8	60.7 ± 1.5	0.3030	0.9593
Length of *Musculus longissimus dorsi* [mm]	66.0 ± 4.7	63.8 ± 7.9	64.9 ± 6.0	1.1843	0.7604
Backfat thickness [mm]	12.0 ± 2.1	11.5 ± 2.7	11.5 ± 2.7	0.4721	0.8562

3.2. Chemical Analyses

Nutritional Value

The data on the chemical composition of meat are shown in Table 4. No effect or statistical differences were detected for the chemical composition of MLD ($p > 0.05$).

Table 4. Chemical composition of *Musculus longissimus dorsi*.

Item	Experimental Groups			SEM	*p*-Value
	Control	WDGS 10%	WDGS 15%		
	% in Meat				
Dry Matter	27.7 ± 0.9	27.4 ± 1.2	27.6 ± 0.5	0.1812	0.3289
Crude Protein	22.9 ± 0.6	23.3 ± 0.5	23.0 ± 0.4	0.0968	0.2711
Crude Fat	2.2 ± 0.4	2.2 ± 0.6	2.2 ± 0.1	0.0732	0.9582
Crude Ash	1.1 ± 0.07	1.1 ± 0.08	1.1 ± 0.01	0.0122	0.7709

3.3. Fatty Acid Profile

The data in Table 5 present the fatty acid composition of the intramuscular fat (IMF) of MLD. No statistical differences were detected for the concentrations of SFAs, MUFAs or PUFAs ($p > 0.05$). Out of all of the examined fatty acids only eicosenoic acid (C20:1n9) exhibited significant differences, where the highest concentration was determined for the control group and the lowest for the WDGS 15% group ($p < 0.05$). AI was the only one of the health-promoting indexes that was determined to be statistically different via the Kruskal–Wallis and the Dunn–Bonferroni tests.

Table 5. Fatty acid profile of intramuscular fat extracted from *Musculus longissimus dorsi* (g/100 g of fatty acids) and values of health-promoting indexes.

Specification	Experimental Groups			SEM	*p*-Value
	Control	WDGS 10%	WDGS 15%		
C10:0	0.12 ± 0.04	0.10 ± 0.00	0.10 ± 0.01	0.005	0.3487
C12:0	0.18 ± 0.09	0.14 ± 0.10	0.12 ± 0.03	0.018	0.3009
C14:0	1.31 ± 0.12	1.45 ± 0.18	1.19 ± 0.10	0.040	0.2160
C16:0	23.81 ± 1.08	24.36 ± 0.85	23.57 ± 1.02	0.233	0.4903
C16:1	3.04 ± 0.24	3.17 ± 0.25	3.29 ± 0.13	0.053	0.1083
C17:0	0.21 ± 0.02	0.19 ± 0.07	0.23 ± 0.04	0.012	0.3038
C17:1	0.21 ± 0.03	0.20 ± 0.08	0.24 ± 0.05	0.013	0.3313
C18:0	12.19 ± 0.83	11.89 ± 0.69	11.35 ± 0.89	0.198	0.4843

Table 5. *Cont.*

Specification	Experimental Groups			SEM	*p*-Value
	Control	WDGS 10%	WDGS 15%		
C18:1n9c	42.86 ± 3.05	43.02 ± 1.03	43.65 ± 1.57	0.465	0.4308
C18:1n7c	3.69 ± 0.32	3.78 ± 0.22	3.83 ± 0.23	0.059	0.4233
C18:2n6c	7.63 ± 1.03	8.29 ± 0.78	8.81 ± 1.04	0.242	0.1475
C18:3n3	0.30 ± 0.05	0.29 ± 0.04	0.30 ± 0.04	0.010	0.8355
C20:0	0.17 ± 0.01	0.15 ± 0.04	0.16 ± 0.02	0.006	0.3039
C20:1n9	0.73 ^{c} ± 0.01	0.43 ^{b} ± 0.05	0.64 ^{a} ± 0.03	0.032	0.0005
C20:2n6	0.27 ± 0.02	0.27 ± 0.03	0.29 ± 0.05	0.008	0.7099
C23:0	0.51 ± 0.12	0.52 ± 0.19	0.58 ± 0.25	0.043	0.7943
SFAs	38.49 ± 1.78	38.8 ± 1.36	37.29 ± 1.94	0.410	0.2714
MUFAs	50.54 ± 3.57	50.59 ± 1.12	51.65 ± 1.95	0.553	0.2636
PUFAs	8.20 ± 1.09	8.85 ± 0.82	9.40 ± 1.08	0.253	0.1477
PUFAs n-3	0.30 ± 0.05	0.29 ± 0.04	0.30 ± 0.04	0.010	0.8355
PUFAs n-6	7.90 ± 1.04	8.56 ± 0.80	9.10 ± 1.06	0.247	0.1475
AI	0.50 ^{ab} ± 0.04	0.51 ^{b} ± 0.01	0.46 ^{a} ± 0.02	0.007	0.0277
TI	1.24 ± 0.09	1.24 ± 0.04	1.15 ± 0.05	0.017	0.0408
S/P	0.67 ± 0.05	0.67 ± 0.02	0.62 ± 0.03	0.009	0.0408
DFA/OFA	2.17 ± 0.15	2.15 ± 0.05	2.29 ± 0.08	0.027	0.0759

SFAs (Saturated fatty acids) = C10:0 + C12:0 + C14:0 + C16:0 + C17:0 + C18:0 + C20:0 + C23:0. MUFAs (Monounsaturated fatty acids) = C16:1 + C17:1 + C18:1n9c + C18:1n7c + C20:1n9. PUFAs (Polyunsaturated fatty acids) = C18:3n3 + C18:2n6c + C20:2n6. PUFAs n-3 (OMEGA-3) = C18:3n3. PUFAs n-6 (OMEGA-6) = C18:2n6c + C20:2n6. Numerical values in the same row marked in pairs with letters abc differ at $p \leq 0.05$.

3.4. Oxidative Status of Meat

The ability to limit lipid peroxidation (TBARS) of MLD varied significantly between groups ($p < 0.05$), and is presented in Figure 2. The lowest concentration of lipid oxidation was observed in the WDGS 10% group, and it was significantly lower compared to the control and WDGS 15% groups. There were no statistical differences between the control and WDGS 15% groups.

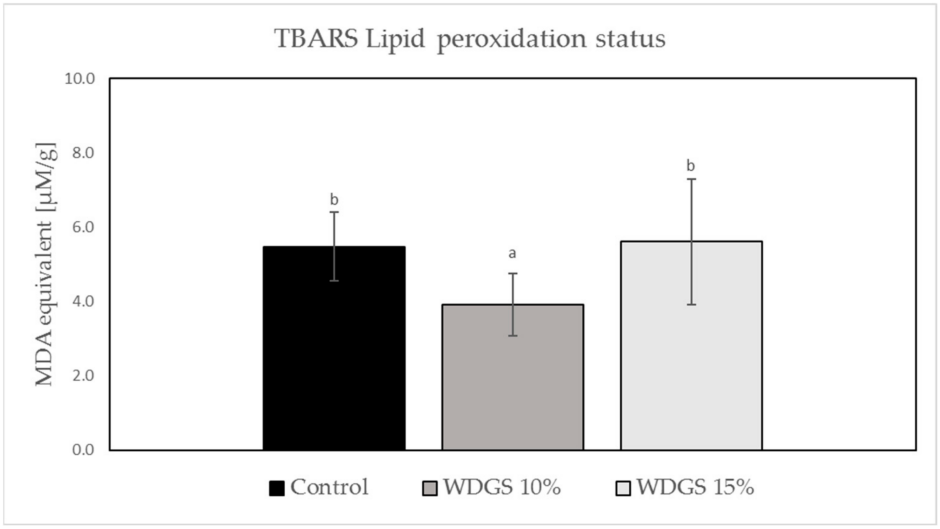

Figure 2. Lipid peroxidation status of *Musculus longissimus dorsi* samples ($p < 0.05$). Numerical values in the same row marked in pairs with letters ab differ at $p \leq 0.05$.

3.5. Meat Quality

As presented in Table 6, meat quality analyses included measurements such as: drip loss, WHC, thermal drip loss, and colorimetry measurements (luminosity; red–green intensity; yellow–blue intensity; hue; chroma). Samples of MLD displayed significant differences for WHC. The highest effluent exhibited samples were from the WDGS 15% group while the lowest were WDGS 10%. The control group did not differ between the former or the latter group ($p < 0.05$). The colorimetry measurement displayed statistical differences for red–green intensity (a*), yellow–blue intensity (b*) and chroma (C*), which were always the highest for the WDGS 10% group and the lowest for the WDGS 15% group ($p < 0.05$).

Table 6. Quality of meat from *Musculus longissimus dorsi*.

Item	Experimental Groups			SEM	*p*-Value
	Control	WDGS 10%	WDGS 15%		
Drip loss (%)	4.88 ± 0.97	5.42 ± 1.29	4.86 ± 0.72	0.1961	0.4028
Water holding capacity (cm^2/g)	22.26 ^{ab} ± 1.73	20.08 ^{a} ± 2.34	23.42 ^{b} ± 2.28	0.4787	0.0096
Thermal drip loss (%)	22.2 ± 3.65	21.63 ± 1.41	20.01 ± 4.40	0.6545	0.3796
L*	51.21 ± 2.22	51.38 ± 1.75	51.96 ± 1.91	0.3791	0.3445
a*	5.54 ^{ab} ± 0.94	5.86 ^{b} ± 0.74	5.03 ^{a} ± 1.09	0.1901	0.0066
b*	4.04 ^{ab} ± 1.10	4.62 ^{b} ± 7.49	3.94 ^{a} ± 6.41	0.1860	0.0180
h*	0.74 ± 0.21	0.80 ± 0.12	0.79 ± 0.14	0.0180	0.3839
C*	6.86 ^{ab} ± 1.12	7.47 ^{b} ± 0.86	6.39 ^{a} ± 1.34	0.2300	0.0033

Numerical values in the same row marked in pairs with letters ab differ at $p \leq 0.05$.

4. Discussion

WDGS has been actively utilized as a feedstuff source for ruminants, in particular cattle, which may be of practical interest for farms located in the vicinity of ethanol plants [4,6,11,35]. However, currently, with liquid feeding becoming more and more widespread in pig farming, WDGS seems as a viable component for pigs' diets. This study further reinforces the assertion that pigs can indeed be fed ensilaged WDGS under a wet lot feeding system, which can partially substitute protein feedstuff and cereal grains. In the WDGS 10% and WDGS 15% groups, the average combined share of soybean and rapeseed meals in the diets was lowered by 25% and 37%, respectively, throughout the entire fattening period. However, according to our study, nothing over about 15% WDGS should be used in the diets of fatteners as it may lead to feed refusals, stunted growth, and subsequently decreased average daily gains. This phenomenon was observed for fatteners which were initially fed 20% WDGS in their diet during the introductory period. This prompted us to decrease the concentration of WDGS by 5% so that the final feed mixture contained 15% WDGS. Similar findings were reported for fatteners being fed concentrations of above 15% DDGS [17]. Interestingly, some authors reported that apparently feeding fatteners with 20% [36] or 30% WDGS [7] did not affect weight gains, feed intake or feed conversion for the former, while for the latter it only affected feed intake and FCR. Additionally, fatteners fed 15% WDGS during the first stage of the fattening period displayed the lowest ADG which might have been explained by the initially lowered feed intake in the introductory period. While not statistically significant, during the second stage of the fattening period there was a tendency toward a slight increase in ADG for the WDGS 15% group, which can be explained by the compensatory growth phenomenon. Moreover, the addition of both concentrations of WDGS did not affect ADG during the entire fattening period. In general, the WDGS 15% group utilized its feed worse than the control group or pigs fed 10% WDGS. Despite the fact that the concentration of crude protein in the

diets was similar overall, and that the amino acid composition of replaced soybean meal is considered to be generally better, fatteners achieved fairly similar ADGs and final body weights. Therefore, it can be deduced that the inclusion of WDGS may in fact enhance the utilization of proteins. The dosage of distillers' grains did not affect the carcass traits: final body weight, hot carcass weight, *Longissimus dorsi* muscle, dressing percentage, depth and backfat thickness, or the chemical composition of the meat: dry matter and crude fat. Similar findings were obtained and described by other authors [18,37,38]. This phenomenon may be explained by an enhanced utilization of nutrients and the well-balanced energy and protein requirements of the diets. The composition of fatty acids is one of the most important measurements of the dietary value of meat. The addition of WDGS did not affect the total composition of the sum of SFA, MUFA and PUFA, including PUFA n-3 and n-6, except for C20:1n9. Moreover, it is noteworthy that WDGS is characterized by a rather high concentration of fat of around 12% DM [39]. WDGS's profile of unsaturated fatty acids is similar to that of corn oil's, where the fat consists of mainly oleic (21.9%) and linoleic acids (45.1%) [40]. In this study no statistical increase or decrease in the fatty acid composition of IMF was found, except for C20:1n9. This contradicts the findings of several authors. Contrary to our findings, Świątkiewicz et al. (2021) [38] state that the SFAs were affected by the addition of distillers' grains, while MUFAs or PUFAs were unaffected. However, according to Harris et al. (2018) [13], SFAs, MUFAs and PUFAs of IMF are affected by distillers' grains. The fatty acid profile is crucial for the determination of health-promoting indexes such as AI, TI, S/P and DFA/OFA [41]. The addition of ensilaged WDGS did not cause any of the health-promoting indexes to worsen. Higher concentrations of WDGS in the diets tended to slightly lower the AI values of IMF, which is beneficial for human consumption, however, the values of TI, S/P, DFA/OFA remained unaffected. According to Alagón et al. (2015) [42], replacing feed concentrate with 20% DDGS does not affect health-promoting indexes. Moreover, the fatty acids composition is responsible for lipid oxidation. One of the factors that may affect lipid peroxidation is the higher composition of unsaturated fatty acids such as PUFA and MUFA [43,44]. Lipid oxidation in creates secondary metabolites such as malonaldehyde (MDA), which are then used in TBARS assay to assess peroxidation [45,46]. The data show that the addition of WDGS into fatteners' diets did not negatively impact the oxidative status of pork meat. In comparison to the control feed, feed containing 15% WDGS did not significantly influence or increase the lipid peroxidation of pork loin. Moreover, pigs fed diets with the addition of 10% WDGS exhibited a significant decrease in lipid peroxidation, which points to the lowest oxidation of all the groups. Although statistically unproven in this study, the higher concentrations of MUFAs and PUFAs in the WDGS 15% group lead to higher TBARS than the WDGS 10% group. The received TBARS values for raw pork were considerably higher than those reported by Papastergiadis et al. (2012) [47]. This study demonstrates that the experimental diets affected only some of the parameters of meat quality. While meat quality is largely unaffected by the addition of WDGS there were statistical differences for WHC. WHC is a meat parameter that can be altered through pH level changes, yet pH was not measured during this experiment. In general the higher meat pH, the higher WHC of meat [48–50]. WHC is a parameter describing the capacity of meat to retain water, which is an important factor since water loss reduces sellable meat/carcass weight, reduces overall meat quality and creates exudative for microorganisms to proliferate [51]. The detected values of WHC (20.08–23.42 cm^2/g) of MLD were higher than the ones (15.2–17.1 cm^2/g) reported by Sońta et al. (2021) [41]. Sońta et al. (2021) [41] utilized the dry lot feeding of fatteners with the implementation of legume seeds into their diets. Meat coloration parameters are one of the most important factors influencing the consumption of meat as the consumer relies heavily on their sensory evaluation before the purchase. In this study, pigs fed 10% WDGS exhibited higher color saturation (C*), and saturation in red (a*) and yellow (b*) than pigs fed 15%. As a general rule, the redness (a*) is influenced mainly by the myoglobin content, while yellowness (b*) is heavily affected by the concentration of IMF [52]. Similarly to a*, saturation (C*) is a parameter responsible for illustrating the formation of oxymyoglobin,

which is an oxidated form of myoglobin [52,53]. Unlike WDGS, DDGS does not seem to affect color parameters [38].

5. Conclusions

The use of WDGS in pig feeding allows for the partial replacement of protein components. In conclusion, the results of this experiment showcased that the addition of ensilaged WDGS from 10% to 15% DM to the fatteners' feed did not cause any adverse effects on pig performance. Even as evidenced by the WDGS 10% group, WDGS may positively affect pork production. During the introductory period pigs fed diets above 15% WDGS decreased their feed intake. Moreover, the addition of ensilaged WDGS does not affect the carcass traits, meat quality, chemical composition of meat or the physiochemical characteristics of the pork. It is worth mentioning that a concentration above 15% WDGS may negatively affect pigs performances such as animal growth and feed intake. Furthermore, the substitution of ensilaged WDGS in fatteners' feed may become a viable and beneficial alternative to partially replace some of the concentrates such as cereal grains or protein feedstuff for liquid-fed pigs.

Author Contributions: Conceptualization, M.R., A.Ł. and M.S.; methodology, A.Ł., M.Z.-G. and M.S.; software, T.N.; validation, A.Ł., T.N. and K.Z.; formal analysis, M.R., W.B. and A.Ł.; investigation, M.R., A.Ł. and M.Z.-G.; resources, A.Ł. and M.S.; data curation, A.Ł., M.Z.-G. and M.S.; writing—original draft preparation, M.R.; writing—review and editing, M.R., A.Ł. and M.Z.-G.; visualization, M.Z.-G. and K.Z.; supervision, A.Ł.; project administration, A.Ł.; funding acquisition, A.Ł. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Pasza PRO: Technologie wykorzystania ubocznych produktów przetwórstwa płodów rolnych, grant number POIR.01.01.01-00-0224/19. The APC was funded by the Warsaw University of Life Sciences grant number 505-50-740100-FN0000-99.

Institutional Review Board Statement: This study was approved by the 2nd Local Animal Research Ethics Committee in Warsaw.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data presented in this paper are available from the authors on request.

Conflicts of Interest: The authors declare no conflict of interest.

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